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Treadwell, Lee

The new Croton aqueduct

[n.p.]

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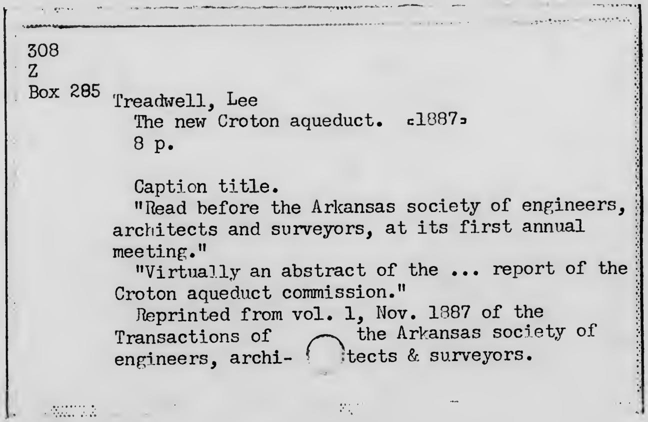

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Box 285 Treadwell, Lee
The new Croton aqueduct. ⌐1887⌐
8 p.

Caption title.
"Read before the Arkansas society of engineers, architects and surveyors, at its first annual meeting."
"Virtually an abstract of the ... report of the Croton aqueduct commission."
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NOTE—SEE TABLES OF PROGRESS, Page 7

This is an exact reproduction of Mr. Treadwell's paper as [illegible] in Volume 1, Number 1, [illegible] of the transactions of the Arkansas Society of Engineers, Architects & Surveyors-

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THE NEW CROTON AQUEDUCT.

BY LEE TREADWELL, FAYETTEVILLE.

[Read before the Arkansas Society of Engineers, Architects and Surveyors, at its first annual meeting.]

[This paper is virtually an abstract of the recently published report of the Croton Aqueduct Commission. The report covers all work done up to January 1, 1887.]

The great increase in population, commerce and manufactures of New York city has rendered her present water supply quite incapable of carrying a sufficient volume to meet the great and increasing demand for pure and wholesome water. On account of the incapacity of the present aqueduct to supply the required volume of water, "the people have been deprived of the ordinary conveniences of domestic life, the public health has been endangered, the security of property from fire has been diminished, and the pursuit of commerce and manufacture has been retarded." Hence the necessity for some means by which this great and increasing demand for pure water might be supplied. The remedy was found in the new Croton aqueduct now in course of construction.

The present aqueduct draws its supply of water from the great Croton watershed. The water is stored in Croton lake, which is formed by the Croton dam, and is drawn off through the aqueduct and delivered at Central Park, New York city.

The insufficiency arises, not from a limited quantity of water furnished by the watershed, but from the incapacity of the present aqueduct to carry the enormous amount required by the city. The aqueduct is capable of delivering 95,000,000 to 98,000,000 gallons every day. This amount, however, is much more than the conduit was designed to carry, in consequence of which a number of settlements causing cracks and considerable leakage has been the result It is worthy of note that these breaks occurred where the conduit was laid in sand or soft earth and not where in firm solid earth or rock.

By the beginning of the year 1883 the complaints of the people and manufactures of the city assumed such an aspect that the State Legislature felt that they would be called upon to consider legislation to secure to the city an additional water supply. They therefore passed a resolution requesting the mayor of New York city to select and appoint, within five days from the passage of the resolution, five citizens of the city who, in conjunction with himself, should without delay examine into the plan prepared by the chief engineer of the Croton aqueduct and other eminent engineers, for a new aqueduct, and "report to that body within twenty days as to the practicability of the proposed plans, the probable cost, the time required for its erection and such other views and recommendations as they might deem proper."

The committee held many meetings and consulted many eminent engineers whose experience in hydraulics and whose knowledge as to the needs and surroundings of New York city was varied and extended by years of experience and observation.

The important part of the committee's report was unanimously agreed upon and they reported, that the plans which they were asked to investigate were practicable and should be adopted with a few slight modifications; that the water should be brought from the Croton watershed; that it should be brought to the city in an underground conduit built in solid rock, when possible, and lined with masonry where the rock was not solid; that the construction should be under the direction and supervision of an aqueduct commission appointed by the legislature from the best citizens of the city.

In compliance with this report the Legislature passed an act "to provide new reservoirs, dams and a new aqueduct, appurtenances thereto, for the purpose of supplying the city of New York with an increased supply of pure and wholesome water." The same body then appointed six commissioners under whose direction and management the aqueduct is being constructed. The mayor, comptroller and commissioner of public works were to compose one-half of the commission.

When the time came for considering the available sources from which an adequate supply of pure water could be drawn no difficulty was experienced. To all who knew anything of the surrounding country the Croton watershed offered the best and only practicable source from which the required amount and quality of water could be drawn. This district is within the jurisdiction of the State; its water has been more carefully studied and is better known than any other; it is pure and wholesome, and a supply of 250,000,000 gallons per day can be obtained from this source much cheaper than from any other. It was once suggested that salt water be introduced for cleansing the streets, gullies and sewers, and for extinguishing fires. This method, however, would have necessitated the laying of a double system of pipes in every street and house into which the salt water should be carried. Furthermore the amount of water required for "extinguishing for a whole year is less than one-half the amount of consumption for one day for other purposes," it seems, therefore, that the facts were against the introduction of salt water so long as an adequate supply of fresh water could be obtained at a reasonsble cost. The diameter of the aqueduct could be increased from 12 feet to 15 feet in diameter, with a two-thirds increase in capacity of flow, at an additional cost of 15 per cent, another item in favor of fresh water.

The great demand made of the present aqueduct can be partially realized when we consider that, when the old aqueduct was built, the population of New York city was less than 350,000 and that to day the population is over 1,300,000. During this growth the consumption of water has increased so much that in many cases where, formerly the water was delivered to the highest floor of buildings, it will now barely run into the lower floor or in some cases into the basements.

STORAGE.

From the statistics of rainfall in the Croton watershed and from the flow of the river, it has been estimated that this source will supply, in the dryest season, 250,000,000 gallons per day. This quantity, however, varies for each day from 10,000,000 to 7,000,000,000 gallons in case of freshets; hence the necessity of having a large storage capacity in order to secure a constant supply at all times.

For storing this water two plans were proposed: (1) To build a high dam at Quaker bridge, making a reservoir large enough to hold the required amount of water; (2) to build as additions to Croton dam a number of smaller dams across the upper part of the river and across the principal tributaries. If the former plan is accepted it is proposed to build the dam of stone laid in hydraulic mortar, to rest on bed-rock, surface of water in reservoir to be 200 feet above mean tide or 33.83 feet above the top of the present Croton dam; the area of the reservoir 3635 acres, and a capacity of 32,000,000,000 gallons above the level where drawn off.

If built the Quaker bridge dam will receive the drainage from the entire watershed, 361 square miles, or 23 square miles more than the present Croton dam. This addition will yield 20,000 gallons per day. It is the cheapest method of storing the required amount of water for a new aqueduct; the estimated cost being $125 per 1, 000,000 gallons capacity, while the estimated cost of the smaller dams in the upper watershed was made in 1879 after very careful examinations and found to be $200 per 1.000,000 gallons. Moreover, the cost of maintaining the single reservoir and guarding it against pollution would evidently be much less than for the smaller ones distributed over a large area.

The necessity of building Quaker bridge dam in order to secure the maximum supply of water is only a question of time. Hence, if built now, it would save an additional expense of about $6,000,000, amount required for the construction of the smaller reservoirs. This amount, moreover, is sufficient to build the high dam. The difficulty of bringing the water down from the small reservoirs in cold weather is also obviated. Another great advantage in having the high dam is the deep settling basin, which is always prized very highly by hydraulic engineers.

The commissioners have not yet decided to build this dam; but a small one, Sodom dam, was completed recently. It was built in order to meet the present demands. In designing this dam all the available literature and data respecting high masonry dams that had been constructed in all parts of the world was collected and carefully examined. "The vital question involved was the establishment of a reliable and economical cross-sectional profile for the dam, requiring mathematical development of form to sustain strains, with and without the pressure of a full reservoir against it."

In proportioning the dam strains for many joints, horizontal and otherwise, were calculated, commencing with the top-layer and developing the profile downwards in proportions and weights capable of resisting increasing pressure and strains on successive joints to the base of the dam.

In order to be thoroughly satisfied of the immediate necessity and practicability of building the Quaker bridge dam, the commission called upon J. B. Jervis, J. B. Francis, General George S. Green, J. W. Adams and R. K. Martin, eminent engineers who were acquainted with the scheme, for their investigations and opinions. All of the gentlemen advised the adoption and immediate construction of the dam.

THE NEW AQUEDUCT.

In regard to the line, the question involved was whether the aqueduct should be constructed along the valley of the Hudson river near the line of the old aqueduct or whether an interior line through the valleys of Saw-mill and Pocanto rivers should be chosen.

The latter of these two routes had the advantage of being shorter, and possessing a solid rock underground gave great advantages in constructing a subterranean conduit. After considering both lines, the aqueduct commission, in April, 1884, approved and adopted a line for the aqueduct now under construction.

This line commences at Croton dam and runs in a southerly direction along the Pocanto and Saw-mill river valleys, across the Harlem, and from thence to the northerly side of Manhattan valley at One Hundred and Thirty-fifth street.

“The general features of the plans for the aqueduct, comprised the construction of a conduit commencing at Croton dam with its mouth 60 feet below high water level in Quaker bridge reservoir, and to discharge into Central Park reservoir, the total fall from the water level of greatest flow in the aqueduct at Croton lake to high water in Central Park reservoir being 33.8 feet for a length of 38 1-8 miles. The interior of the conduit was to have a cross-sectional area such that its flowing capacity would be equal to that of a circle 14 feet in diameter, and to run mainly in tunnel, built on a uniform grade of 7-10 of a foot per mile to station No. 1272-20, near shaft No. 20.

“The tunnel was then to run to and under the Harlem river as an inverted syphon, and to continue under pressure of flow to One Hundred and Thirty-fifth street, on the north side of Manhattan valley. From this point the water is to be conveyed in iron pipes to Central Park reservoir.”

On account of the conduit being lower from station 1272 to Central Park than it is from Croton river to station 1272, the diameter of the conduit was decreased at that point from 14 feet to 12 feet 3 inches in diameter. The increased flow allowed the reduced conduit to deliver the required 250,000,000 gallons per day. Part of this increased grade will also be used in forcing 250,000,000 gallons through the tunnel aqueduct under Harlem river, permitting a still further reduction to 10.5 feet in diameter at that point. “These reductions in the size of the conduit under pressure of flow reduced not only the cost, but also the total hydraulic pressure, which these portions of the aqueduct must sustain.”

In explaining the details we can do no better than quote from the report of the chief engineer, which is as follows:

“There are three gate-houses for controlling and regulating the water supply through the aqueduct, the largest and most elaborate one at Croton dam entrance; the second at the south end of the tunnel conduit at One Hundred and Thirty-fifth street, where the pipe lines begin, and the third at the final terminus at the Central Park reservoir.

“Along the line shafts were located at distances varying from 6200 to 7800 feet. The tunnel grade, in all its length, from Croton lake to Harlem river, twice reaches the level of the grade. These points constitute open portals numbered as shafts; that of Pocantico No 9; that of Tibbit's Brook No. 18. At each of these open portals a waste gate-house is placed, besides which there are two others, one at Ardsley, where the tunnel is near enough to the earth's surface to admit of discharging its contents through a culvert in open cut, and the fourth waste weir occurs at High bridge, where, far below ground, it is emptied through an adit-tunnel into the Harlem river.”

Previous to letting the contract, diamond drill explorations were made in order to obtain necessary data on which to base contract plans. These explorations were quite elaborate and exhaustive, having been continued for a period of one year or more.

“Field parties were organized at the outset and equipped with accurate instruments. They were supplied with carefully prepared detailed instructions to establish a final alignment of precision, by placing bolts and monuments and level benches to insure great accuracy of lines and grades, which afterwards be transferred from such surface lines and levels down the shafts, into the tunnels to guide the work when in progress. Alignment bolts of copper were ordered to be placed in solid ledge rock when possible, or in the center of stone monuments, whose foundations were to be built below the surface of frost. After the bolts and monuments were placed, the lines were again run and marked with a fine center punch and hair lines. Much of this had to be accomplished at night by sighting to plumbet lamps, to prevent errors from radiation of reflected heat rays of the sun during the daytime in hot weather. The accuracy of the work has been proven by the exactness with which many of the adjacent tunnel headings have come together.”

On November 1st, the headings between shafts 2 and 3 met. When there was but eight feet of rock remaining between the two headings, an Ingersoll rock drill was set on the same alignment and grade in each of the headings; drilling was then commenced, and when each had gone on half of the way through the points of the drills met and touched each other.

“The levels of precision to secure reliable final level benches between Croton river and Central Park reservoir were established with great care. They were run over the hills, on the new aqueduct line, from Croton dam to city ends of the line, then back over the same ground to the starting point, testing within a few thousandths of a foot. They were then run down to Central Park on the even grade of the old aqueduct, branching off at many points to test the bench bolts on the new aqueduct. The accuracy of the future tunnel grades was, therefore, made reliable, having been tested three times, and afterwards again checked by the division engineer, each on his own division.”

After a careful consideration of length of line that could be covered by each engineering party during construction, the line was divided into six divisions between Croton dam and Harlem river. This was done on the 23d of December, 1884, and these divisions were placed in charge of their respective division engineers, who were supplied with detailed plans, tables giving grades for every station, exact location, forms and sectional areas of all masonry to be constructed, which had been accurately calculated and prepared in the chief engineer's office. Division offices were rented along the line; field parties were at once appointed, organized and equipped with instruments and appliances for each division, and these parties were then sent to test their line and level benches in preparation for starting the work.

After all the preliminary forms were complied with, bids for all that portion of the aqueduct between Croton and Harlem rivers were received, and the contracts were awarded on the 13th of December, 1884, as follows: Sections 2, 3, 4 and 5, to Brown, Howard and Co.; sections 6, 7, 8 and 9, to O'Brien & Clark. The remaining sections, 10 and 11, up to Harlem river, were awarded to Heman Clark.

The contracts required that work should commence on these sections within twenty days from date of letting, and to the satisfaction of all this requirement was complied with in each case. Much solicitude was felt in regard to the character and efficiency of the plant that the contractors would provide. “This fear, however, was allayed when it became known that they had ordered makers of the highest reputation to furnish new and powerful mining appliances. Brown, Howard & Co. selected the Ingersoll manufacture, while Heman Clark and O'Brien & Clark preferred the Rand plant, consisting of air compressor engines, power drills, pumps, hoists, blowers, etc. The contractors equipped the 24 shafts along the 28 1-4 miles of aqueduct between the Croton and Harlem rivers, each with a separate plant. One set of air compressor engines, however, furnished power for shafts No. 0 and 1. Another set supplied No. 7, 8 and 9. Each of the other 19 shafts separate compressors for the power drills.”

During the winter of 1884-85, the above appliances were transported, and the boilers, compressed air and hoisting engines, were all set in masonry. Meanwhile the derricks and iron buckets had been supplied, and continued to be used for excavation, until shaft head-frames could be prepared and erected for machine hoisting.

From this time the work vigorously progressed by night and day on all the sections at the shafts, portals and open cuts.

Section 1, which comprises the gate-house at Croton lake, and with it its short by-pass tunnel, was awarded July 30, 1885. On the 27th of January, 1886, contracts for the construction of section 12, of the new aqueduct which was from station 1490-63, near shaft 24, under the Harlem river to station 1557, including shafts No. 25, 26, 27 and 28, were awarded; and sections 13 and 14, including shafts No 29, 30, 31 and 32, were also awarded at the same time.

Work began at once on these sections, which placed the whole length of the tunnel masonry aqueduct under construction by contract, from Croton dam to the southern terminus at One Hundred and Thirty-fifth street, where the pipe lines begin.

The character of the earth and rock in the tunnel is clearly shown by the following extract from the report of the commissioners:

CHARACTER OF THE ROCK AND EARTH IN THE TUNNEL.

"The dip of the rock strata along the line is generally to the southeast; it varies from verticle planes to angles of from 10 to 20 degrees from the vertical; the strike of the rock closely follows the alignment of the tunnel or crosses it at an acute angle. The tunnel headings are therefore driven against the ends of the strata, which increases expense and retards progress Had the dip and strike of rock been at right angles to the alignments, then the excess of excavation over the amount required would have been less, and the tunnel could have been excavated close to the prescribed form of cross-section. The experience has been that even with skillful blasting accurate and close tunnel excavations are rather the exceptions than the rules, because often when the roof is blasted in the heading to nearly approach the simi-circle required, later on the blasting of the bench under it has caused the haunches of the curved roof to fall, owing to the nearly verticle and thin stratification changing the curved roof to a nearly flat surface. This has rendered necessary a larger proportion of timbered ground than was anticipated. The amount of unskillful tunnel work has not been large, considering the rate of progress demanded by the contractors. The heavy blasting required to make such progress, shattered the rock far back and necessitated increased thickness of masonry lining to sustain the roof and sides of the tunnel. On a large portion of the line slippery talc was found, which made the ground heavy and dangerous. Nearly every variety of tunnel experience has been met with so far. The northern half of the conduit is further below the surface in hard granitic and syenitic rock, but it is often broken and blocky, requiring strong timber supports. In the north heading of shaft No. 2, 80 feet of heavy timbering was crushed, leaving a chasm of 30 feet above the roof, although the rock was hard. All the headings on the upper part of the aqueduct have contained some rock of this character. On the southern part of the aqueduct much difficult ground has been encountered. The tunnel under Saw-mill river was driven through sandy clay by polling pieces in timber sections; this was difficult work and was well managed. South of this river, at shaft 12 B, the tunnel strikes into a treacherous limerock which continues nearly to shaft 14. About 300 feet south of shaft 13 a fissure 12 feet broad was met with, filled with red clay, water and fine sand, which broke to the surface 150 feet above, leaving a funnel-shaped cavity on the surface. This was passed but a short distance when a broader and more serious fissure of the same character was encountered which also broke in, half filling the tunnel back to 13 with clay and water; this ground was recovered and masonry constructed to hold the tunnel. The same experience has been met with in the north heading, shaft 14. Additional shafts between 13 and 14 have been recommended. These shafts are required to increase the number of points of attack through this ground, which is the most difficult to tunnel on the entire line. From shaft 14 to Harlem river the rock may be classed as soft laminated, micaceous gneiss and mica schist, with stretches of hard garnetic gneiss. At shaft 18, south, the disintegrated talcase rock was so heavy as to crush the strongest timbering used on the line for a length of 40 feet, which was afterwards successfully tunneled and lined with six rings of brick arching on the roof, side walls and bottom. The ground then continued to be treacherous and heavy until shaft 19 was reached. Additional shafts 18 1-2 and 19 1-2 were excavated to increase the rate of progress in the timbered ground. The sunken portions of the aqueduct are in comparatively strong rock from shaft 20 to 24. but directly at shaft 20 the rock is blocky."

The following table shows the comparative rate of progress in four of the headings, also for the entire line:

HIGHEST AVERAGE RECORD IN SINGLE HEADING FOR THE LAST FOUR MONTHS, UP TO JULY 3, 1886, WITH DIFFERENT DRILLS.

SHAFT	HEADINGS		WEEKLY	MONTHLY
23	South	With Ingersoll drills exclusively	48.8	219.8
16	South	With *G & D. drills exclusively	37.7	169.5
13	North	With Rand & Ingersoll drills together	37.3	167.8
20	South	With Rand drill exclusively	33.9	152.5

AVERAGE MONTHLY PROGRESS.

For the last four months on the entire line, 47 headings	141.8
In thirty headings using Ingersoll drills exclusively	153.6
In five headings using Ingersoll & Rand drills together	130.9
In seven headings using Rand drills exclusively	122.8
In four headings using G. & D. drills exclusively	137.5

*Graydon & Denton.

SUMMARY OF WORK COMPLETED JANUARY 1, 1887.

No. of shafts completed	35	
Greatest depth of shaft	350	feet
Least depth of shaft	28.2	feet
Aggregate depth of shaft	4491.4	feet
Greatest depth of tunnel below surface	475	feet
Least depth of tunnel below surface	0	feet
Average depth of tunnel below surface	170	feet
Total tunnel excavated	21.696	miles
Open cut excavated	0.964	miles
Excavation completed	22.66	miles
Total unexcavated	8.2	miles

Total masonry being completed:

Arch in lineal feet	16,713
East wall lineal feet	32,382
West wall lineal feet	31,881
Invert lineal feet	7,722

Excavations completed at Croton gate-house:

Earth	7,031	cub yds.
Rock	51,619	cub. yds.
Total	58,650	cub. yds.

In a report on "A Water Supply for New York and Other Cities of the Hudson Valley," by J. T Fanning, C. E., the following tables are given.

MEAN AND MEASURED CONSUMPTION OF WATER DAILY IN NEW YORK.

ESTIMATE BY MEAN CURVE OF CONSUMPTION, DAILY.		MEASURED CONSUMPTION.*	
YEAR	Million Gallons.	YEAR	Million Gallons
1842	12.0	1842	12.0
1860	49.0		....
1861	51.5		...
1862	54.0		....
1863	56.5	1863	54.4
1864	59.2		....
1865	62.0		....
1866	64.8	1866	66.0
1867	67.5	1867	72.0
1868	70.5	1868	78.0
1869	73.5	1869	75.0
1870	77.0	1870	70.0
1871	80.0	1871	79 0
1872	83.5	1872	81.0
1873	87.3	1873	88.0
1874	91.0	1874	92.0
1875	95.0	1875	95.0

* Commissioner's Report, August 12, 1879.

ESTIMATE OF FUTURE CONSUMPTION OF WATER IN NEW YORK CITY BY PROLONGING THE MEAN CURVE OF PAST CONSUMPTION.

YEAR	Million Gallons	Increase Million Gallons	YEAR	Million Gallons	Increase Million Gallons
1876	98.0	......	1889	168.0	7.0
1877	102.0	4.0	1890	176.0	8.0
1878	106.0	4 0	1891	184 0	8.0
1879	110.5	4.5	1892	193.0	9.0
1880	115.0	4.5	1893	202.0	9.0
1881	120.0	5.0	1894	212.0	10.0
1882	125.0	5.0	1895	222.0	10.0
1883	130.5	5.5	1896	234 0	12.0
1884	136 0	5 5	1897	246.0	12 0
1885	142.0	6.0		.....	......
1886	148 0	6.0	1898	258.0	12.0
1887	154.0	6.0	1899	272.5	14.5
1888	161 0	7.0	1900	290.0	17.5

As the consumption of water in New York city in 1875 was equal to that of the full capacity of the present conduit, the increase in measured consumption of course stopped at that time

The evidence of this record is that a new series of water famines are likely to follow within a few years after the completion of the new Croton conduit, unless the Croton is supplemented from some other source.

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